Journal of Biosafety and Biosecurity 1 (2019) 128–133

Contents lists available at ScienceDirect

Journal of Biosafety and Biosecurity

journal homepage: www.elsevier.com/locate/jobb

Short Communication

Establishment of the key Technical Indicators of Positive Pressure Biological Protective Clothing

Hao Limei [a,b], Zhang Zongxing [a,b], Yi Ying [a,b], Qi Jiancheng [a,b], Zhou Yongyun [c,*], Wu Jinhui [a,b,*]

[a] Institute of Medical Support Technology, Academy of System Engineering, Academy of Military Science, Tianjin 300161, China
[b] National Bio-protection Engineering Center, Tianjin 300161, China
[c] China National Accreditation Center for Conformity Assessment, Beijing 100101, China

ARTICLE INFO

Article history:
Received 9 December 2018
Received in revised form 13 August 2019
Accepted 19 August 2019

Keywords:
Biosafety
Protective clothing
Positive pressure
Standard

ABSTRACT

Objective: Trying to establish the key technical indicators related to positive pressure biological protective clothing (PPBPC), providing technical support for the establishment of PPBPC standards in the future.
Method: We examined the protection standard systems established by the major standards organizations in China and other developed countries. We also analyzed the technical indicators of the gas-tight chemical protective clothing and ventilated protective clothing against particulate radioactive contamination which closely related to PPBPC. And tested the performance of a set of imported dual-purpose PPBPC to verify the fit of its technical indicators with the standards. We aimed to identify the status of China's standards in the area of personnel protection and put forward feasible suggestions for the production of PPBPC in China.
Results: Developed countries in Europe and North America have a complete system of standard protective clothing. China should also strengthen the construction of standard protective clothing, especially PPBPC.
Conclusion: With the improvements in infectious disease prevention and control on a global scale, the demand for PPBPC continues to increase and consideration should be given to the establishment of standards for this.

1. Introduction

The Ebola virus disease epidemic, the Middle East Respiratory Syndrome pandemic, and the Zika virus outbreak in recent years have sounded the alarm. The globalization of infectious diseases has become a new form of epidemic.[1–4] The World Health Organization (WHO) has initiated the establishment of a global early warning network and global public health intelligence network to response to infectious diseases, and has strongly urged countries worldwide to cooperate with each other to jointly prevent and control infectious diseases.[5,6] The protection of the lives and health of frontline workers is a key point in the prevention, control, response, and research regarding communicable diseases. Schumacher et al. conducted a survey which showed that specialist registrars had the best knowledge of PPE requirements for severe acute respiratory syndrome (SARS), but had less so about those for anthrax, plague, Ebola virus, and smallpox.[7] Respiratory protective equipment is still the preferred PPE when dealing with Ebola virus.[8] The PPBPC is currently the world's most commonly used high-grade PPE. The PPBPC, which provides the wearer with high-level body and respiratory protection, should be widely used in laboratories requiring high-level biosafety and during infectious disease rescue efforts.

The performance of the PPBPC directly affects the wearer's safety. Manufacturers generally adopt the latest standards to guide the development and production of positive pressure protective clothing, to ensure high-quality performance. However, there is currently no international standard for PPBPC. To facilitate better understanding of the current worldwide standards related to the PPBPC, we reviewed the standards for protective clothing of developed countries around the world and compared these with those in China.

2. Standard profile

First, we searched for Chinese and foreign standards in the Wan Fang database, using "protective suit", "chemical protective suit",

* Corresponding authors at: China National Accreditation Center for Conformity Assessment, Beijing 100101, China (Z. Yongyun), Institute of Medical Support Technology, Academy of System Engineering, Academy of Military Science, Tianjin 300161, China (W. Jinhui).

E-mail addresses: zhouyy@cnas.org.cn (Y. Zhou), wujh@npec.org.cn (J. Wu).

https://doi.org/10.1016/j.jobb.2019.08.003
2588-9338/

or "nuclear suit" as search terms. We retrieved 706 criteria, including 477 current standards. Of the 477 standards currently in force, 56 are from the International Organization for Standardization (ISO), 68 from the American Society for Testing and Materials (ASTM), 42 from the European Committee for Standardization (CEN), and 34 from the Chinese National Standards. The current standards set by three organizations—the ISO, ASTM, and CEN—include a total of 166 protective standards, accounting for one-third of the world's protective field standards. Therefore, developed countries in Europe and North America can be considered authorities in this field.

The current standards retrieved included basic standards, product standards, and testing standards for various types of protective clothing. Research with respect to PPBPC usually refers to the provision of anti-chemical and anti-radioactive contamination positive pressure protective clothing and standards. Requirements, inspection, and testing methods for materials are established, which encompass assembly to overall performance. We focused on standards related to the development, production, and evaluation of PPBPC.

The key technical indicators of positive pressure protective clothing refer mainly to the series of standards issued by ISO, ASTM, and CEN (Tables 1–3). In 1994, the CEN issued EN 270:1994 and EN 464:1994. EN 464:1994 stipulated the pressure detection method for airtight protective clothing. In 1994, the United States issued NFPA 1994, which is currently the updated 2001 version. In 1998, the European Union issued the standard EN 1073-1, which regulates the performance of the air supply system, and the intake and exhaust valves. In 2002, EN 943-1:2002 was issued, which addressed the material utilized by and the overall protection of gas-tight protective clothing (Type 1 and Type 2), with the performance and test methods being specified in detail. In 2002, the ISO issued ISO 16602:2002, which was revised in 2007. In 2003, the CEN issued EN 14126, which regulates the performance requirements and test methods of virus protective clothing, and specifies the requirements for the viral permeability of protective clothing fabric. The ASTM published ASTM F1671-07, the updated version of which is ASTM F1671/F1671M-13, ASTM F1670-08, and ASTM F2588-12 in 2007, 2008, and 2012, respectively. In 2015, the CEN updated its standard EN 943-1:2002 and issued EN 943-1:2015.

3. International standards on key indicators of positive pressure protective clothing

The key indicators mostly refer to the standard indicators according to the standards for protective clothing against radioactive contamination and chemical protective clothing.

Table 1
Standards issued by the International Standards Organization relating to PPBPC.

Standard	Standard name
ISO 13688-1998	Protective clothing—General requirements
ISO 13982-1 AMD 1-2010	Protective clothing for use against solid particulates – Part 1: Performance requirements for chemical protective clothing providing protection to the full body against airborne solid particulates (type 5 clothing)
ISO 13982-1-2004	Protective clothing for use against solid particulates – Part 1: Performance requirements for chemical protective clothing providing protection to the full body against airborne solid particulates (type 5 clothing)
ISO 13982-2-2004	Protective clothing for use against solid particulates – Part 2: Test method of determination of inward leakage of aerosols of fine particles into suits
ISO 13994-2005	Clothing for protection against liquid chemicals – Determination of the resistance of protective clothing materials to penetration by liquids under pressure
ISO 13995-2000	Protective clothing – Mechanical properties – Test method for the determination of the resistance to puncture and dynamic tearing of materials
ISO 13996-1999	Protective clothing – Mechanical properties – Determination of resistance to puncture
ISO 13997-1999	Protective clothing – Mechanical properties – Determination of resistance to cutting by sharp objects
ISO 15384-2003	Protective clothing for firefighters—Laboratory test methods and performance requirements for wildland firefighting clothing
ISO 16073-2011	Wildland firefighting personal protective equipment—Requirements and test methods
ISO 16602-2007/Amd 1-2012	Protective clothing for protection against chemicals—Classification, labeling and performance requirements
ISO 16603-2004	Clothing for protection against contact with blood and body fluids—Determination of the resistance of protective clothing materials to penetration by blood and body fluids—test method using synthetic blood
ISO 16604-2004	clothing for protection against contact with blood and body fluids—Determination of the resistance of protective clothing materials to penetration by blood-borne pathogens—test method using Phi-X174 bacteriophage
ISO 17491-1-2012	Protective clothing—Test methods for clothing providing protection against chemicals—Part 1 Determination of resistance to outward leakage of gases (internal pressure test)
ISO 17491-2-2002	Protective clothing—Test methods for clothing providing protection against chemicals—Part 2 Determination of resistance to inward leakage of gases (inward leakage test)
ISO 17491-3-2008	Protective clothing—Test method for clothing providing protection against chemicals—Part 3: Determination of resistance to penetration by a jet of liquid(jet test)
ISO 17491-4-2008	Protective clothing—test methods for clothing providing protection against chemicals—Part 4: Determination of resistance to penetration by a spray of liquid (spray test)
ISO 17491-5-2008	Protective clothing—Test methods for clothing providing protection against chemicals—Part 5: Determination of resistance to penetration by a spray of liquid (manikin spray test)
ISO 22608-2004	protective clothing—Protection against liquid chemicals—Measurement of repellency, retention, and penetration of liquid pesticide formulations through protective clothing materials
ISO 22609-2004	Clothing for protection against infectious agents—Medical face masks—Test method for resistance against penetration by synthetic blood (fixed volume, horizontally projected)
ISO 22612-2005	Clothing for protection against infectious agents—Test method for resistance to dry microbial penetration
ISO 6529-2013	Protective clothing—Protection against chemicals—Determination of resistance of protective clothing materials to permeation by liquids and gases
ISO 6530-2005	Protective clothing—Protection against liquid chemicals—Test method for resistance of materials to penetration by liquids
ISO 6942-2002	Protective clothing—Protection against heat and fire—Method of test: Evaluation of materials and material assemblies when exposed to a source of radiant heat
ISO/TR 11610-2004	Protective clothing—Vocabulary

Table 2
Standards issued by the European Committee for Standardization relating to PPBPC.

Standard	Standard name
EN 1073-1-2002	Protective clothing against radioactive contamination—Part 1: Requirements and test methods for ventilated protective clothing against particulate radioactive contamination
EN 1073-2-2002	Protective clothing against radioactive contamination—Part 2: Requirements and test methods for non-ventilated protective clothing against particulate radioactive contamination
EN 14126-2016	Protective clothing—Performance requirements and tests methods for protective clothing against infective agents
EN 14325-2016	Protective clothing against chemicals—Test methods and performance classification of chemical protective clothing materials, seams, joins and assemblages
EN 464-1994	Protective clothing for use against liquid and gaseous chemicals, including aerosols and solid particles – Test method: Determination of leak-tightness of gas-tight suits (internal pressure test)
EN 943-2-2002	Protective clothing against liquid and gaseous chemicals, including liquid aerosols and solid particles – Part 2: Performance requirements for "gas-tight" (Type 1) chemical protective suits for emergency teams (ET)
EN ISO 17491-3-2008	Protective clothing—Test method for clothing providing protection against chemicals—Part 3: Determination of resistance to penetration by a jet of liquid (jet test)
EN ISO 17491-4-2008	protective clothing—test methods for clothing providing protection against chemicals—Part 4: Determination of resistance to penetration by a spray of liquid (spray test)
EN ISO 22612-2005	Clothing for protection against infectious agents—Test method for resistance to dry microbial penetration
EN 270-1995	Respiratory protective devices—Compressed air line breathing apparatus incorporating a hood—Requirements, testing, marking.
EN 464-1994	Protective clothing for use against liquid and gaseous chemicals, including aerosols and solid particles – Test method: Determination of leak-tightness of gas-tight suits (internal pressure test)
EN 943-1-2015	Protective clothing against dangerous solid, liquid and gaseous chemicals, including liquid and solid aerosols_Part 1: Performance requirements for Type 1 (gas-tight) chemical protective suits.

3.1. Terms and definitions

Gas-tight chemical protective clothing: Chemical protective clothing that is leak-tight when tested in accordance with the internal pressure test given in BS EN 464:1994.

Airtight chemical protective clothing was classified into three categories in EN943-1:2015, which are Type 1a, Type 1b, and Type 1c suit.

The definition of PPBPC refers to that of airtight chemical protective clothing, and the powered air positive biological protective clothing corresponds to Type 1b airtight chemical protective clothing (Type 1b protective clothing). The long tube aeration type PPBPC corresponds to Type 1c airtight chemical protective suit (Type 1c protective clothing).

3.2. Material performance parameters

There are several standards in countries outside China that stipulate the physical properties of materials and test methods. The main indicators of protective clothing fabrics and window materials are shown in Table 4. A set of imported dual-purpose PPBPC was destroyed, and the physical properties of the fabric was tested, the results met the parameters specified by the standard.

3.3. Overall performance of protective clothing

3.3.1. Nominal protection factor/inward leakage

The protective factor is the most critical technical parameter of PPBPC. The United States Respiratory Protection Committee divides the protective factors into design protection factors, work protection factors, and special state protection factors.[9] EN 1073-1:2002 specifies that the nominal protection factor for airtight protective clothing should be greater than 50,000 and the inward leakage (IL) rate less than 0.002%. The protection factor is the reciprocal of the IL rate obtained during all activities. There is no requirement for a specific IL rate for long tube aeration-type PPBPC. Safety mainly depends on the quality of the air supply system. For powered air positive biological protective clothing, the IL rate should be less than 0.0025%.

Table 3
Standards issued by the American Materials and Experiments Association relating to PPBPC.

Standard	Standard name
ASTM 11.03-2011	Occupational health and safety—Protective Clothing
ASTM F 1291-15	Standard test method for measuring the thermal insulation of clothing using a heated manikin?
ASTM F1001-12	Standard guide for selection of chemicals to evaluate protective clothing materials.
ASTM F1194-1999 (2010)	Standard guide for documenting the results of chemical permeation testing of materials used in protective clothing
ASTM F1296-08 (reapproved 2015)	Standard guide for evaluating chemical protective clothing
ASTM F1301-1990 (reapproved 2006)	Standard practice for labeling chemical protective clothing
ASTM F1342M-05 (reapproved 2013)	Standard test method for protective clothing material resistance to puncture
ASTM F1359-16	Standard test method for liquid penetration resistance of protective clothing or protective ensembles under a shower spray while on a manikin
ASTM F1383-12	Standard test method for permeation of liquids and gases through protective clothing materials under conditions of intermittent contract
ASTM F1407-1999a (2006)	Standard test method for resistance of chemical protective clothing materials to liquid permeation—Permeation cup method
ASTM F1461-2012	Standard practice for chemical protective clothing program
ASTM F1494-2014	Standard terminology relating to protective clothing
ASTM F1670-08	Standard test method for resistance of materials used in protective clothing to penetration by synthetic blood.
ASTM F1671/F1671M-13	Standard test method for resistance of materials used in protective clothing to penetration by blood-borne pathogens using Phi-X174 bacteriophage penetration as a test system
ASTM F1819-07 (reapproved 2013)	standard test method for resistance of materials used in protective clothing to penetration by synthetic blood using a mechanical pressure technique
ASTM F2053-00(2017)	standard guide for documenting the results of airborne particle penetration testing of protective clothing materials
ASTM F2061-12	standard practice for chemical protective clothing: wearing, care, and maintenance instructions
ASTM F2130-11	Standard test method for measuring repellency, retention, and penetration of liquid pesticide formulation through protective clothing materials
ASTM F2588-12	Standard test method for Man-in Simulant(MIST) for protective ensembles
ASTM F2668-16	Standard practice for determining the physiological responses of the wearer to protective clothing ensembles
ASTM F2815-2010	Analysis of chemical penetration parameters of protective clothing materials by computer program
ASTM F739-2012e1	Standard test method for permeation of liquids and gases through protective
NFPA 1994-2001	Standard on Protective Ensembles for Chemical/Biological Terrorism Incidents
NFPA 1999-2003	Standard on Protective Clothing for Emergency Medical Operations

Table 4
Positive pressure protective clothing fabric performance requirements.*

No	Test items	Indicators	Related standards
1	Abrasion resistance	The number of cycles required to produce damage > 500 (no less than 3 level)	ASTM 4966, EN 388, ISO 5470, EN 14325
2	Flex cracking resistance	>15,000 times (no less than 4 level)	ASTM F392, ISO7854, EN 14325
3	Tear resistance	>40 N (no less than 3 level)	ASTM D 2261, ISO 4674, EN 14325
4	Tensile strength	>250 N (no less than 4 level)	ASTM D5034, ISO 13935-1, EN 14325
5	Puncture resistance	>50 N (no less than 3 level)	ASTM D2582, ISO13995, EN 14325
6	Resistance to ignition	burning time < 5 s	ASTM1358, EN 532, ISO15025, EN 14325
7	Resistance to liquid penetration	<10%	ASTM F739, EN369, ISO6529, EN 14325
8	The seam strength between the main fabric	>300 N	ASTM D751, ISO13935-2, EN 14325
9	Seam strength between protective clothing and accessories	>75 N	EN 14325
10	Blocking blood	no penetration in 1 h	ASTM F1819, ASTM F1670, ISO16604

Note: *the requirements in the standard EN 943-1:2015, the listed grades are classified by this standard. The specific data listed are the data in EN14325-2016 and ISO16604-2004.

3.3.2. Leak tightness

Leak tightness is another key indicator of positive pressure protective suit. The basic principle of the leak tightness test is to use a pressure decay method, that is, after inflating the protective clothing to a prescribed pressure, the leak tightness of the protective suit is evaluated by measuring the change in pressure within a specified time. The protective suit is first inflated to 1750 Pa and then maintained at 1650 Pa. The degree of pressure drop is measured within 6 minutes; an acceptable drop in pressure is no more than 300 Pa (3 mbar) (Table 5). Tested the leak tightness of this imported clothing, its pressure reduction value is less than 200 Pa.

3.3.3. Internal static pressure

EN 943-1:2015 specifies that the internal static pressure of the protective suit should not exceed 400 Pa. A pressure gauge is used to test the internal pressure of the protective suit under static conditions at the maximum designed air supply. For the long tube aeration-type PPBPC, the internal static pressure tested was 140∼172 Pa and 242∼274 Pa respectively in the minimum flow rate and in the maximum flow rate. For air-powered PPBPC, the internal static pressure was 133∼150 Pa.

3.3.4. Noise

The positive pressure biological protective clothing will generate noise when worn. EN 1073-1:1998 and EN14594:2005 stipulate that the maximum noise level inside the positive pressure protective suit at the maximum flow rate should not exceed 80 dB(A). In general, when the noise level is higher than 75 dB (A), the wearer should use communication and noise protection equipment.[10] For the long tube aeration-type PPBPC, the noise was 71.6 dB(A) and 79.5 dB(A) respectively in the minimum flow rate and in the maximum flow rate. For air-powered PPBPC, the noise was 67.2 dB(A).

3.3.5. Air supply system

For the long tube aeration-type PPBPC, which should be able to be quickly connected with the air supply system, the air intake valve should be adjustable and installed in a position that is convenient for the wearer to operate. The minimum adjustment flow of the intake valve should meet the minimum design static pressure of the protective suit. At the maximum air supply flow, the air supply system ensures that the average static pressure inside the protective clothing does not exceed 400 Pa.

3.3.6. Electric air supply system

For air-powered PPBPC, the air supply provided by the powered air supply system should not be lower than 350 L/min, and the filter used should have a filtration efficiency of more than 99.99%. Electric air supply systems should also have both a low battery alarm and a low air volume alarm. The supply air volume of the tested air supply system was 380∼400 L/min, which met the requirements of the standard.

3.3.7. Exhaust valve

The positive pressure bio-venture exhaust device is composed of one or more exhaust valves that meet the requirements for maintaining the positive pressure of the air supply and exhaust gas balance. The exhaust valve mounted on the protective suit should be able to work normally after the overall air-tightness and IL rate are tested, and the IL rate should be maintained to meet the design requirements. The exhaust valve should be designed as a one-way valve. EN943-1:2015 stipulates the performance index of the exhaust valve. Under a pressure of −1000 Pa, the pressure leakage caused by the exhaust valve within 1 min should not exceed 100 Pa. The connection strength between protective clothing and the exhaust valve should be able to withstand tensile forces of no more than 150 N for 10 s.

3.3.8. Practical performance evaluation

The MIST is one of the most widely used methods for evaluating protective clothing. ASTM F2588-12 specifies the standard test method (MIST) for protective clothing using human body simulation tests. MIST provides an assessment of the overall protective clothing system including the materials, seams, zippers, and other accessories. Ormond believes that the ability to detect lower levels of permeation or penetration under current standard conditions pushes analytical methods and instruments to their operating limits. Therefore, to more accurately evaluate airtight protective clothing, some changes to the standard method must be considered. Here we discuss potential approaches to make the MIST method more suitable for evaluating fully hermetic protective clothing. These methods include increasing the contact dose, changing the air sampler properties, enhancing the analytical detection limits, or any combination of these.[11] Gao et al. believe that ASTM F 2588-06 provides a detailed description of the test procedure, but does not provide specific requirements for the design of the test chamber. Based on a literature survey of existing test chambers, and a review of the current and proposed standards and test methods, cabin design requirements will depend on the test

Table 5
Comparison of relevant indicators of different standards.

Indicator	GB 24539-2009	EN 943-1-2015	ISO 16602-2007	EN1073-1-1998	NFPA 1994
Inward leakage rate	Gas or aerosol: NA Liquid Leakage Performance: No leakage during liquid injection 1 h	The long tube aeration type positive pressure bio-protective suit: NA The powered air type positive pressure bio-protective suit:<0.05%	The long tube aeration type positive pressure bio-protective suit: NA The powered air type positive pressure bio-protective suit:<0.05%	Request test, Graded Leakage Rate Data	<0.02%
Static pressure	NA	The positive pressure < 400 Pa when the air supply flow is 300 L/min	The positive pressure < 400 Pa when the air supply flow is 300 L/min	Average pressure difference < 1000 Pa, peak pressure difference < 2000 Pa, at the Maximum air flow	NA
Leak Tightness	Pressure drop is not more than 20% of initial pressure 1000 Pa in 4 min	Pressure drop does not exceed 300 Pa in 6 min, when the test pressure is 1650 Pa	Pressure drop is not more than 20% of initial pressure 1000 Pa in 4 min	NA	Pressure drop is not more than 20% of initial pressure 1000 Pa in 4 min
Noise	NA	<80 dB (A) at Maximum air flow	<80 dB (A) at Maximum air flow	<80 dB (A)	NA
Air supply system	NA	Meet the requirement of EN 12021	NA	The connection strength of all parts of the gas supply system and protective clothing should be ≥250 N Air flow should not cause discomfort to the wearer	NA
Intake valve	NA	Minimum adjustment flow: >Design minimum flow	Minimum adjustment flow: >Design minimum flow	Minimum adjustment flow: >Design minimum flow	NA

method chosen. Since the test conditions for aerosol/particle and vapor integration tests vary widely, a single chamber is unlikely to be used to test for all types of protective clothing.[12]

EN943-2015 stipulates that airtight protective clothing should pass the practical performance test when worn by personnel for a testing time of 30 minutes.

3.3.9. Ergonomics

ASTM F2668:2011 stipulates the methods for testing the effect of protective clothing on human physiological indicators. Lee et al. believe that breathability and water vapor transmission rate are the indices of protective clothing for thermal comfort.[13] Fukazawa has developed a movable, sweating manikin. With the aid of this human body model, heat and water vapor resistance of the protective suit can be measured in different temperature and humidity environments to characterize the comfort of the human body.[14]

4. Chinese standards for protection

Compared to international standards, there are few domestic standards available for reference. The standard references in the development of PPBPC are GB24539-2009, GB30864-2014, GB/T 23465-2009, and RB/T 199-2015. In the performance test standards for protective clothing, there are a number of standards for the direct conversion of international standards, such as GB/T 20655-2006/ISO 13996:1999, GB/T 20654-2006/ISO 13995:2000, and YY/T 0689-2008/ISO 16604:2004.

5. PPBPC products in China and other countries

With increasingly frequent outbreaks of infectious diseases and the advances in infectious disease research, the number of biosafety level 4 (BSL-4) laboratories worldwide has increased. Therefore, there is an increasing demand for PPBPC. Some biosafety laboratories have led to outbreaks owing to poor management, further increasing people's awareness of the need for risk prevention.[15] Choosing suitable protective clothing for BSL-4 laboratories is very important. Kümin et al. designed an experiment to compare models of different brands of PPBPC. Their results showed that there is no perfect product; there were positive and negative aspects of all products tested. This is also the case with the present study.[16] China has a late start in researching positive pressure biological protective equipment. Currently, completed BSL-4 laboratories have adopted imported products. Since the "Twelfth Five-Year Plan" period, Chinese researchers have succeeded in overcoming the main technical problems of PPBPC and have developed positive pressure PPE that meets the international standards. Wang D conducted a performance comparison between a positive pressure biological protective clothing (type B) produced in China and a suit (type A) produced abroad. Both suits exhibited a similar performance in terms of convenience, comfort, noise, and so on, and met the current operational requirements for high-level biosafety laboratories.[17]

At present, PPBPC can provide a high level of protection to wearers in terms of technology. The question that remains is, how can it be widely applied to front-line rescue personnel in an outbreak? This requires national attention and multisectoral cooperation, including financial resources for supporting, training, and educating. Hanoa et al. believe that the steps from "safe enough" to "absolutely secure" seem to be insurmountable in most countries owing to cost and logistics.[18,19]

6. China's standard formulation for positive pressure bioprotective clothing

China currently does not have special standards for positive pressure bioprotective clothing. In future, it is necessary to improve the construction of standard systems for protection areas and to carry out research and preparation of positive pressure bioprotective clothing standards. This will help in the development and production of positive pressure bioprotective clothing, and will also help promote the prevention and control of infectious diseases in China, as well as research on the pathogenic organisms associated with these diseases. Only by protecting the lives of front-line workers can we effectively carry out the tasks needed for infectious disease prevention and control.

7. Conclusion

Establishment of a standard system and formulation of product standards are crucial for product development and production. With improvement in infectious disease prevention and control on a global scale, the demand for PPBPC continues to increase, and the establishment of standards that are applicable to PPBPC should be considered. With the development of new materials and the application of new technologies, safety and intelligent use should be continuously improved based on ensuring the safe development of PPBPC. Product updates and the revision of standards complement each other. We hope that the standards organizations in China and in other countries will consider these current needs and establish special standards for this type of protective clothing, and facilitate and promote its development and production.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by Major infectious diseases such as AIDS and viral hepatitis prevention and control of major projects (2017ZX10304403-004); the National Key Research and Development Program of China (2016YFC1201405).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobb.2019.08.003.

References

1. Min Seob Sim MD, Gabyong Jeong MD, Lee TR, et al. Emergency department workers' perceptions of effectiveness and reported compliance of infection control measures after middle east respiratory syndrome outbreaks. *J Korean Soc Emergency Med*. 2016;27:328–335.
2. Olson CK, Lwamoto M, Perkins KM, et al. Preventing transmission of Zika virus in labor and delivery settings through implementation of standard precautions – United States. *Mmwr*. 2016;65:290–292.
3. Boland TS, Polich E, Connolly A, et al. Overcoming operational challenges to Ebola case investigation in sierra leone. *Global Health Sci Pract*. 2017;5:456–467.
4. Wong CH, Stern S, Mitchell SH. Survey of Ebola preparedness in Washington state emergency departments. *Disaster Med Public*. 2016;10:662–668.
5. Vong S, Samue IP, Gould P, et al. Assessment of Ebola virus disease preparedness in the WHO South-East Asia Region. *B World Health Organ*. 2016;94:913–924.
6. WHO Epidemic intelligence – systematic event detection world health organization web http://www.who.int/csr/alertresponse/epidemicintelligence/en/ doi:10.3892/br.2018.1037.
7. Jan S, Bond AR, Valentine W, et al. Survey of UK health care first Respondersâ knowledge of personal protective equipment requirements. *Prehospital Disaster Med*. 2015;30:254–258.
8. Wizner K, Stradtman L, Novak D, et al. Prevalence of respiratory protective devices in us health care facilities: implications for emergency preparedness. *Workplace Health Safe*. 2016;64:359–368.
9. Johnston AR, Myers WR, Colton CE, et al. Review of respirator performance testing in the workplace: issues and concerns. *Am Ind Hyg Assoc*. 1992;53:705–712.
10. Chen Y, Wang L, Jin L, et al. Noise reduction and personal protection in intensive noise equipment area of methanol production enterprises. *Noise Vib Con*. 2015;35:140–144.
11. Ormond RB. Considerations for applying man-in-simulant test methodologies for the evaluation of fully encapsulating chemical protective ensembles. In: Shiels B, Lehtonen K, eds. *Performance of Protective Clothing and Equipment, 10th Vol: Risk Reduction through Research and Testing, vol 1593*. American Society for Testing and Materials Special Technical Publications; 2016:212–232.
12. Coles GV. Review of chamber design requirements for testing of personal protective clothing ensembles. *J Occup Environ Hyg*. 2007;4:562–571.
13. Lee S, Obendorf SK. Barrier effectiveness and thermal comfort of protective clothing materials. *J Text I*. 2007;98:87–97.
14. Fukazawa T, Lee G, Matsuoka T, et al. Heat and water vapour transfer of protective clothing systems in a cold environment, measured with a newly developed sweating thermal manikin. *Eur J Appl Physiol*. 2004;92:645–648.
15. Wurtz N, Papa A, Hukic M, et al. Survey of laboratory-acquired infections around the world in biosafety level 3 and 4 laboratories. *Eur J Clin Microbiol*. 2016;35:1247–1258.
16. Kumin D, Krebs C, Wick P. How to choose a suit for a BSL-4 laboratory-the approach taken at SPIEZ LABORATORY. *Appl Biosafety*. 2011;16:94–102.
17. Wang D. Performance test of positive pressure bio-protective suits for high-level biosafety laboratories. *JHV&AC*. 2017;47:43–47 (In Chinese).
18. Cassir N, Boudjema S, Roux V, et al. Infectious diseases of high consequence and personal protective equipment: a didactic method to assess the risk of contamination. *Infect Cont Hosp Ep*. 2015;36:1485–1486.
19. Hanoa RO, Moen BE. Ebola care and lack of consensus on personal protective respiratory equipment. *Workplace Health Saf*. 2016;64:48–50.